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Systemic Opportunities to Improve Older Pedestrian Safety: Merging Crash Data Analysis and a Stakeholder Workshop

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Abstract

This paper presents a framework for improving older pedestrian safety in regard to serious (fatal and incapacitating) crashes, using Oregon as a case study. On review of state and federal practices pertaining to older pedestrian safety, 4 years of crash data identified 112 older ($\geqslant$65 years) pedestrian serious injury crashes. These data were explored for factors that might be addressed systemically using two methods. First, raw frequencies in the crash data were assessed to determine trends and crash-related factors that are overrepresented. Second, a random forest analysis was conducted to determine important variables for predicting older pedestrian serious injury crashes. Using these crash-related factors, a workshop was held with 18 local stakeholders and experts. As part of the workshop, key crash trends, potential causations, and potential countermeasures by priority of implementation were determined based on perspectives from workshop participants. Three key systemic solutions were identified to improve older pedestrian safety, including improving pedestrian visibility and illumination, implementing treatments for left turns, and shortening pedestrian crossing distances across the state. The framework presented in the current study could be adopted by other agencies to systemically address a wide variety of safety concerns.

Keywords

pedestrians, bicycles, human factors, planning and policy, safety

In 2018, 6,907 people aged 65 and older were killed in traffic crashes in the United States, which accounted for 19% of all traffic fatalities. Between 2009 and 2018, older pedestrian fatalities increased by 65% overall (*1*). Crashes involving older pedestrians and motor vehicles are more likely to result in a fatality when compared with other age groups because of their greater physical frailty (*2*) and because they are particularly susceptible to collisions with motor vehicles owing to their slower walking speeds, difficulty meeting situational demands, and being at increased risk of falling while walking (*3*). Some older pedestrians may also have an inhibited ability to make safe road crossing judgments and decisions resulting from visual and hearing degradation combined with cognitive decline (*3*). Studies show that when crossing a street, older pedestrians accept shorter time gaps in oncoming traffic as vehicle speeds increase (*4*).

Identifying where infrastructure improvements need to be made to accommodate older pedestrians is a challenge for many agencies. Successful pedestrian programs rely on older pedestrians self-reporting problems with pedestrian infrastructure in their respective communities (*2*). Lowering speed limits on roadways, separating pedestrians by time and space (for example, utilizing protected or leading pedestrian intervals at signalized intersections), increasing the visibility of pedestrians to

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drivers, installing pedestrian countdown signals, and reducing vehicle speeds on roadways with high pedestrian volumes, are all highly effective ways to increase safety for older pedestrians (*3–7*). However, the success of these strategies is dependent on the in situ context, such as cases of lowered speed limits and whether there is a significant proportion of older pedestrians in the population, which may render these strategies to be less effective (*8*).

In Oregon, from 2013 to 2016, 112 pedestrian fatalities and serious injury crashes occurred. Owing to the rate per capita increases of traffic fatalities and serious injuries for older drivers and pedestrians 65 years of age and older, the Special Rule for Older Drivers and Pedestrians in the Fixing America's Surface Transportation (FAST) Act was triggered (*9*). This rule required agencies to develop systemic strategies to address year on year increases. This paper documents a framework for developing strategies to address older pedestrian crashes.

Four years of older pedestrian crash data in Oregon were analyzed to determine trends and factors overrepresented in the raw crash data that resulted in fatal and serious injury crashes. A random forest analysis was conducted to determine important factors in predicting older pedestrian fatal and serious injury crashes. Using the crash factors that were identified as overrepresented and important predictors of older pedestrian serious injury crashes, a list of countermeasures was developed. Crash factors were matched to potential countermeasures based on cost and anticipated implementation duration. Finally, a workshop was conducted with 18 key stakeholders and experts who are responsible for policy and design guidance to identify opportunities for improving policies and procedures to increase older pedestrian safety.

Methods

The framework for developing policy recommendations for improving older pedestrian safety consists of four steps. Older pedestrian crash characteristics were summarized based on records in the Oregon crash data from 2013 to 2016. As part of the descriptive analysis, a random forest model was constructed to identify variable importance in older pedestrian crashes. Following several recent publications from National Highway Transportation Safety Administration (*10–12*), a series of age groups were compared with older pedestrian crashes as follows: 16 years to 24 years, 25 years to 44 years, and 45 years to 64 years.

Next, a comprehensive list of potential countermeasures was identified from the literature. Key sources include the Crash Modification Factors (CMFs) Clearinghouse and Oregon Department of Transportation's (ODOT's) All Roads Transportation Safety (ARTS) program (*13*, *14*). These countermeasures were summarized by category, associated CMFs, their rating, and their effectiveness. Not all possible countermeasures have a quantitative CMF, especially those related to policy or education. The scope of the countermeasure (i.e., policy-driven, project-level, systemic) and whether it is currently listed in one of ODOT's systemic approaches was also indicated. The countermeasures were then matched to crash factors identified from the crash data analysis.

A workshop was hosted with the objectives of (a) bringing together the various stakeholders and experts with responsibilities for policy and design guidance that relate to older pedestrian safety; (b) presenting the results of the data analysis, best practices (identified in the literature review), and potential countermeasures (obtained from CMF Clearinghouse and ODOT's ARTS program); and (c) identifying possible opportunities for improving policies and procedures at ODOT. In consultation with the ODOT research coordinator and the Technical Advisory Committee (TAC), a list of participants was developed. The TAC consisted of five professionals with technical expertise in the subject area (a highway safety coordinator, a signing engineer, a representative from ODOT's Older Road Users Program, a representative from the ODOT Department of Motor Vehicles Medical Program, and a safety and design engineer from Federal Highway Administration). In addition to the ODOT personnel who were responsible for the policy and design guidance pertaining to older pedestrian safety, the research team also invited representatives from counties that were overrepresented in either older driver or older pedestrian crashes, and from agencies engaged with improving older pedestrian (or driver) safety, such as the American Automobile Association (AAA), the American Association of Retired Persons (AARP), and the League of Oregon Counties. A total of 31 stakeholders and experts were invited to participate in the workshop.. Eighteen stakeholders and experts (including the TAC) attended the workshop.

The 18 participants were divided into four groups and three activities had been designed for the participants to elicit feedback. During the first activity, participants at each table independently reviewed crash data information sheets and documented the patterns that seemed notable. Next, participants discussed with their groups the crash trends/overrepresentations that they individually identified as unexpected, or expected, and speculated on the causation. The participants then identified the most important trend or overrepresentations from each table's perspective and recorded them on a response sheet. For the second activity, participants were asked to imagine that they were either the governor or ODOT director for a day and, ignoring cost and feasibility, to brainstorm the changes that they would make to improve older pedestrian safety. The participants were provided with a list of categories to aid the brainstorming process. These categories included licensing and assessment, education and awareness, intersections, roadway design and signing, roadway lighting, and aging in place. Participants were then asked to discuss their proposed solutions in their designated groups and determine whether there were any shared ideas. Those shared ideas were documented on the data sheet at each table. For the final activity in the breakout session, participants individually reviewed the countermeasure list using their own expertise to highlight the countermeasures that would be implementable as a systemic treatment, through policy changes, or design guidance. Finally, the participants discussed systemic actions or changes to specific design standards or policies and documented these using the data sheets provided at each table.

Following the breakout sessions members of the research team synthesized findings from each group pertaining to older pedestrian crash trends and brainstormed solutions. These results were presented back to the participants. Based on feedback obtained about the proposed solutions from the participants, the research team created posters with the proposed solutions aggregated by category. Participants were then asked to use three different colored post-it notes: each color represented a priority level to rank their top-three proposed solutions. The recommendations and proposed solutions are further detailed in Monsere et al. (*15*).

Results

The results from the crash data analysis are presented first, followed by the workshop findings.

Crash Data Analysis

An analysis of the crash data from 2013 to 2016 yielded 112 fatal and serious injury crashes for pedestrians. Figures 1 and 2 present the results of a basic descriptive analysis of the crash data. The majority of older pedestrian fatal and serious injury crashes occurred from 3:00 to 5:59 p.m. (26.8%) or from 6:00 to 8:59 p.m. (21.4%). The largest percentage of older pedestrian fatal and serious injury crashes took place on Fridays (roughly 24%). The majority of older pedestrian fatal and serious injury crashes happened on urban roadway classifications. Specifically, 34% occurred on urban principal arterials, 25% on urban minor arterials, and 15% on urban major collectors. For rural classifications, the highest percentage observed was approximately 6% on rural principal arterials and approximately 6% on rural major collectors. The term "pedestrian action" describes what the pedestrian was doing, their condition, or other factors affecting the individual at the time of the crash (*15, 16*). The majority of pedestrian actions occured at or near intersections, the roadway characteristic with the highest proportion of older pedestrian fatal and serious injury crashes. Approximately 24% of older pedestrians were crossing between intersections when the crash occurred, about 23% were crossing at an intersection with no traffic signal, and roughly 21% were crossing at an intersection with a traffic signal. Nearly 52% occurred during clear conditions, about 29% happened during cloudy conditions, approximately 14% took place under rainy conditions, and roughly 5% occurred during foggy conditions. Approximately 62% of older pedestrian fatal and serious injury crashes involved a male, and roughly 38% involved a female.

Next, older pedestrian fatal and serious injury crashes were compared with fatal and serious injury crashes for other age groups, namely, 16 to 24 years, 25 to 44 years, and 45 to 64 years. Except for the 16- to 24-year age group, all other age groups showed increasing trends of pedestrian fatal and serious injury crashes, as seen in Figure 3.

To determine variable importance in regard to older pedestrian fatal and serious injury crashes, a random forest analysis was conducted. The use of a random forest, or other machine learning method, to identify important predictors and/or complement traditional models has become prevalent in transportation safety literature (*17–30*). The current study applied this approach to identify important variables in predicting older pedestrian serious injury crashes.

Variable importance refers to variables that are deemed most important for predicting older pedestrian serious injury crash outcomes based on the metrics detailed below. A random forest analysis is an ensemble-based machine learning technique (technique in which multiple models are created and then combined to produce improved results). This method utilizes a set of data, in which a dependent variable and a set of explanatory variables are defined. The explanatory variables are then used to predict the dependent variable through the random forest analysis. In the case of the current study, the dependent variable was binary (1 if the older pedestrian sustained a fatal or serious injury, 0 otherwise), and the set of explanatory variables were the crash characteristics. Through the prediction process of the random forest analysis, variable importance was determined.

Variable importance is assessed by two metrics: mean decrease in accuracy and mean decrease in the Gini index. These are often referred to as accuracy-based importance and Gini-based importance, respectively. Accuracy-based importance is associated with the

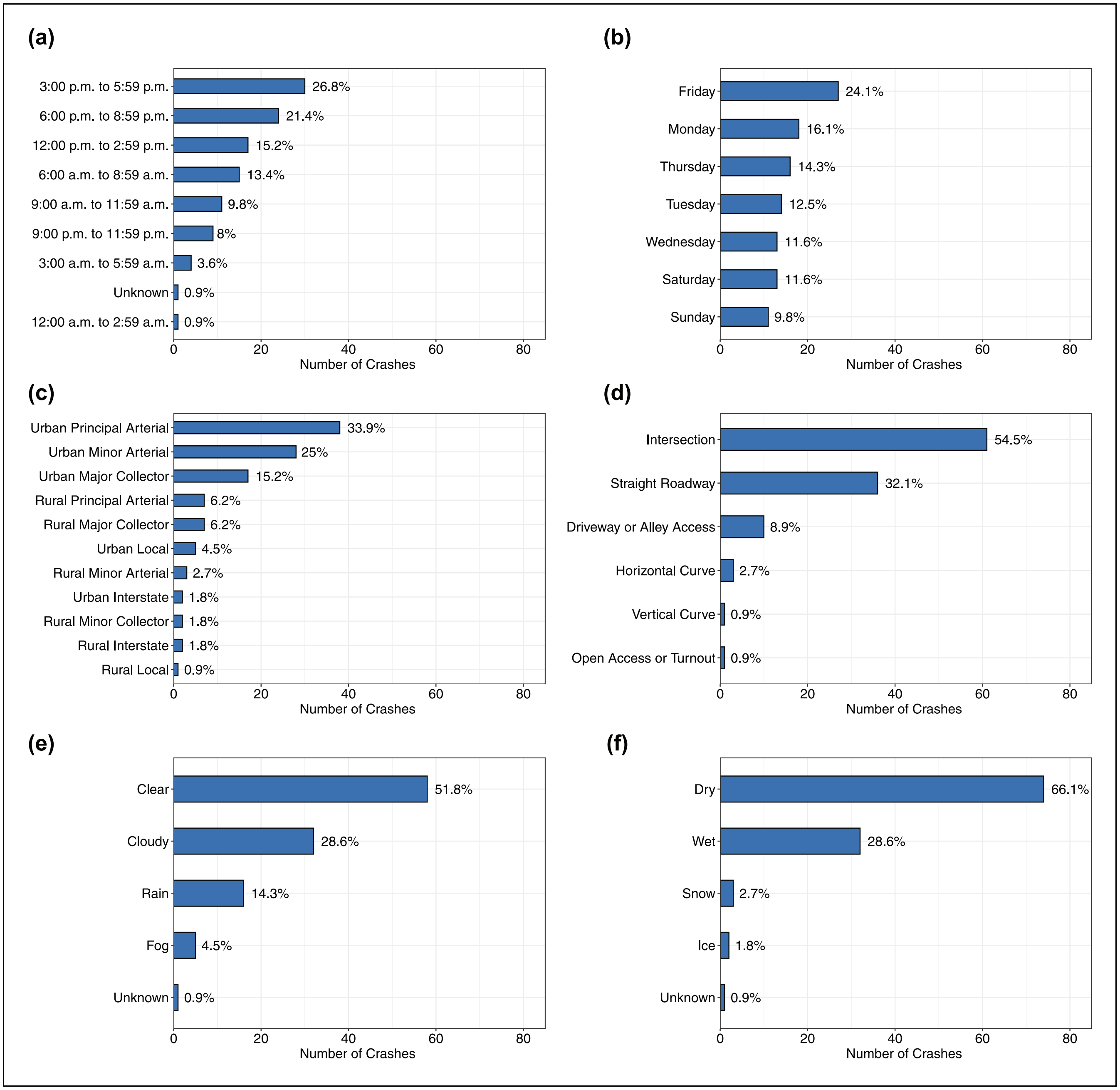

Figure 1. Older pedestrian fatal and serious injury crashes and (*a*) time of day, (*b*) day of the week, (*c*) roadway classification, (*d*) road characteristic, (*e*) weather condition, and (*f*) road surface condition.

prediction accuracy of a specific outcome (*31*). This is computed during the out-of-bag error calculation (a method to measure prediction error on each training sample) in the random forest algorithm (*32*). The higher the accuracy because of the exclusion of a specific variable, the more important that variable is (*32*, *33*). The Gini index (or coefficient) refers to the measure of each variable in relation to the contribution of homogeneity (i.e., reduction in variance) in the tree nodes and leaf nodes of the random forest (*32*). Variables that result in tree nodes with a higher homogeneity lead to a higher decrease in the Gini index.

The use of a random forest in this work stemmed from the disadvantages of decision trees. The major disadvantage of decision trees is their susceptibility to overfitting and generally being nonrobust (*34*). On the other hand, random forests, as stated previously, use an ensemble-based learning technique to generate stronger and more

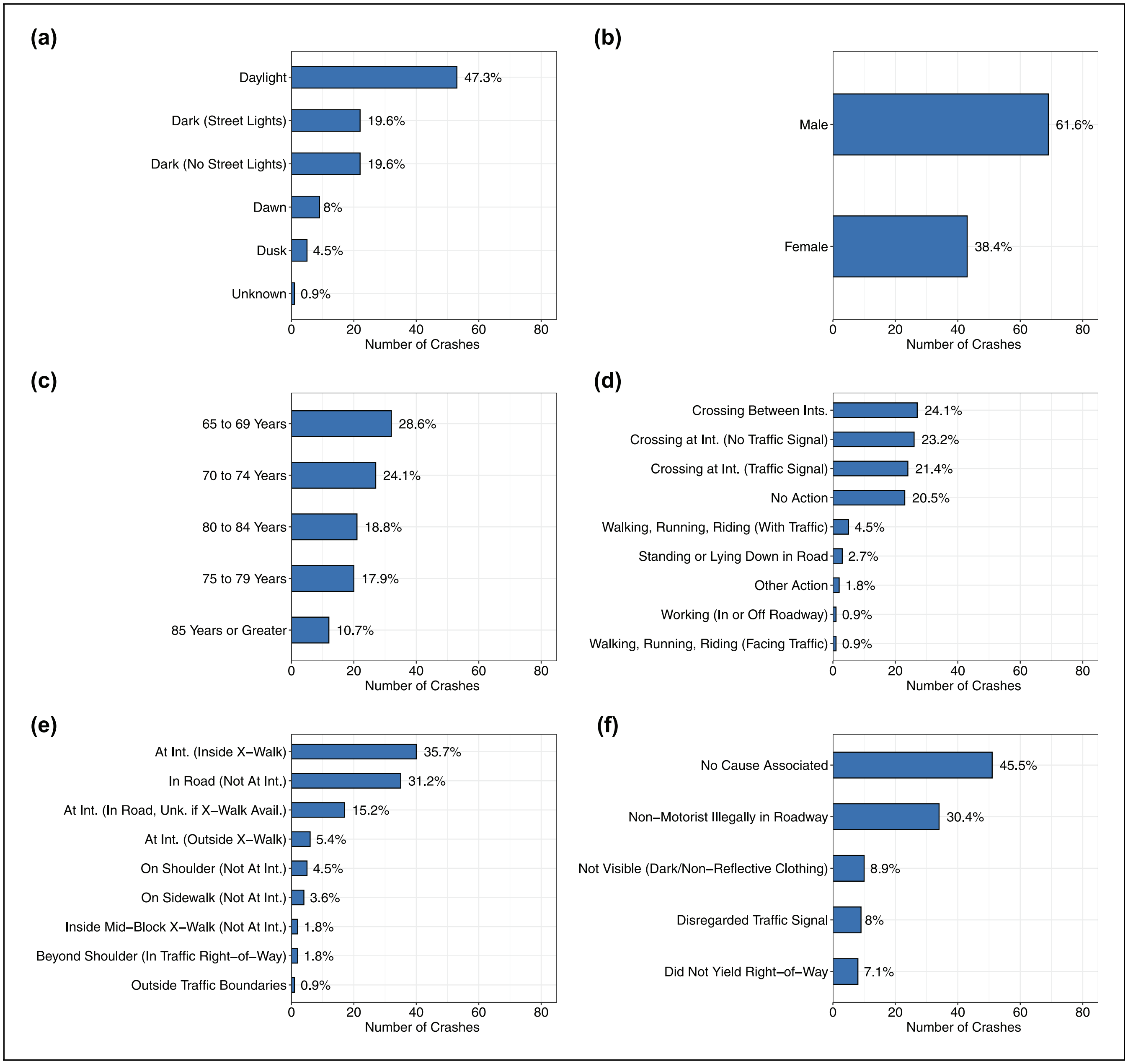

Figure 2. Older pedestrian fatal and serious injury crashes and (*a*) lighting condition, (*b*) gender, (*c*) age, (*d*) pedestrian action, (*e*) pedestrian location, and (*f*) pedestrian-level crash cause.

robust models (*34*). This is accomplished using multiple decision trees and averaging the results.

Table 1 presents the results of the random forest analysis. Shown are the five most important variables for the two variable importance metrics. Based on the mean decrease in accuracy, the most important variables for older pedestrian serious injury crash prediction were dark lighting conditions with no streetlights, intersection crashes, crashes in which the pedestrian was at an intersection and inside the crosswalk, cloudy weather, and daylight conditions. The most important variables in

Table 1. Variable Importance on Older Pedestrian Fatal and Serious Injury Crashes Based on Random Forest Analysis

Top important variables based on mean decrease in accuracy	Top important variables based on Gini index
1. Dark (no street lights)	1. Urban principal arterial
2. Intersection	2. Urban minor arterial
3. At intersection (inside crosswalk)	3. Dark (no street lights)
4. Cloudy	4. Cloudy
5. Daylight	5. Illegally in roadway

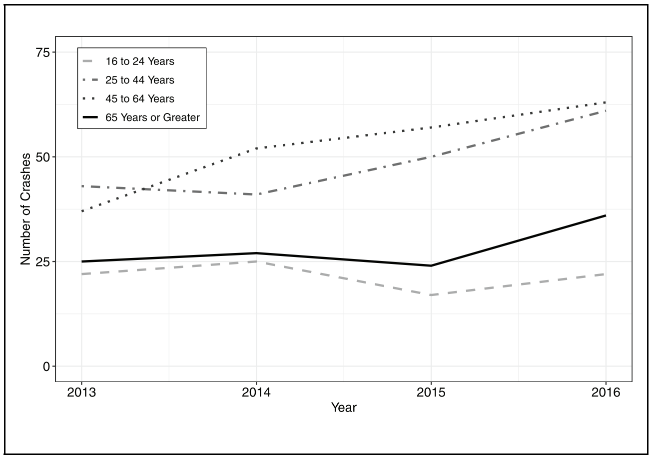

Figure 3. Pedestrian fatal and serious injury crashes by age group.

Table 2. Most Selected Important Crash Trends by Stakeholders

Crash trend	Times selected
Crossing between intersections	2
Daylight	2
Urban areas	2

relation to the Gini index were roadway classification (urban principal arterials and urban minor arterials), dark lighting conditions with no streetlights, cloudy weather, and crashes in which the pedestrian was illegally in the roadway. Two crash-related characteristics were determined to be important for both metrics: dark lighting with no streetlights, and cloudy weather.

Workshop Findings

Stakeholders and experts at the workshop were tasked with three activities, each to be completed and documented by the four groups. Workshop findings are presented by activity and group, followed by a summary of responses that were consistent among groups. The first activity involved each group documenting important patterns in the crash data materials provided to each group. The crash data materials included tables and plots pulled from crash data analysis. Specifically, each group was directed to "Discuss the crash trend/overrepresentation you identified as unexpected or expected. Take notes on your observations and feel free to speculate on causation." Additionally, Activity 1 asked each group to "Identify the most important trend/overrepresentations from the perspective of your group. Make brief notes on the response sheet for your group." Tables 2 and 3 show the important crash trends and potential causations as identified by the stakeholders and experts. These tables represent vote counts by group and potential causations by group, not individual participants. Only one group identified lighting and crossing while not in the intersection. In relation to expected or unexpected crash trends, and potential causation, three trends were identified most often: (1) crossing between intersections, (2) daylight, and (3) urban areas. Workshop participants speculated on potential causations of crashes in which older pedestrians were crossing between intersections, including jaywalking, crossing with no signal, and dificulty estimating speeds and gaps. Likewise, workshop participants speculated on potential causations of older pedestrian crashes that occurred on urban classifications: specifically, pedestrians may be crossing parallel to the mainline. One group posed questions for consideration in future research, such as whether at-fault older pedestrian crashes are a result of low enforcement; whether rural facility crashes are related to older pedestrians checking their mail (physical), and whether there is any correlation between older pedestrians and being homeless that could result in increased crashes.

Table 3. Potential Causation of Most Selected Crash Trends

Crash trend	Potential causation
Crossing between intersections	Jaywalking
	Crossing with no signal
	Harder to estimate speed and gaps
Urban areas	Crossing parallel to mainline

Table 4. Most Frequent Proposed Solutions for Older Pedestrians

Proposed solution	Groups selected
Access management, driveway spacing	3
Crosswalk spacing	3
Lighting/visibility at intersections	3
Crossing visibility	3
Turn restrictions	2

For Activity 2, each group was directed, "As a group, discuss your proposed solutions. Determine whether there are any shared ideas. Make brief notes on the datasheet for your group."

A summary of the most frequently proposed solutions for Activity 2 is shown in Table 4. Table 4 represents counts by group, not individual participants. Of the solutions proposed, four solutions were proposed by at least three groups. The first solution proposed by three groups was access management and/or driveway spacing. One group proposed access management specifically with a

Table 5. Potential Solutions for Older Pedestrian Safety by Priority

Solution	Top priority	Second priority	Third priority
Intersections			
Extended crossing times	0	1	1
Shorter crossing distances/curb extensions/medians	**2**	1	**6**
Adequate pedestrian crossing at regular intervals	1	**4**	**3**
Increased use of protected left-turns (eliminate permissive movements)	**3**	**6**	**5**
Midblock crossings	0	0	0
Education			
Educate on crosswalk use	0	0	1
Roadway lighting			
Illumination to increase pedestrian visibility	**3**	**4**	1
Roadway design			
Lower speeds	**2**	2	2
Grade separate at intersections	0	0	0
Eliminate free-flow turns and right-turn slip lanes	0	**4**	0
Eliminate driveway access close to intersections	**3**	2	0
Make pedestrian safety more of a priority	1	1	0
Other			
Better transit route and stops	1	1	2
Reduce barriers to obtaining rides	1	0	2

Note: Values in ■ indicate countermeasures with the highest number of top-priority votes.
Values in ■ indicate countermeasures with the highest number of second-priority votes.
Values in ■ indicate countermeasures with the highest number of third-priority votes.
The number being in bold is simply to highlight the number in addition to the color scheme.

focus on reducing driveway density. The remaining two groups that proposed access management and/or driveway spacing as a solution did not provide additional comments. However, one group proposed removing driveways from T-intersections. The second solution proposed by three groups was crosswalk spacing. The second group proposed an "adequate" crosswalk spacing, each with additional protection (e.g., Rectangular Rapid Flashing Beacons (RRFBs), signals). The third group proposed an increase in marked or enhanced crosswalk spacing but did not provide additional comments. The final group proposed crosswalk spacing frequency, with an emphasis on spacing at consistent, safe intervals. The third solution proposed by three groups related to lighting/visibility at intersections. The first group proposed higher visibility for pedestrians at intersections (this group also proposed wider waiting areas on the curb and better sightlines). The second group also proposed additional lighting but did not provide additional comments. The third group proposed improved intersection lighting with the premise of increasing driver expectations of encountering pedestrians. This group also proposed improved lighting at midblock crossings and along the roadway. The final solution proposed by the three groups was crossing visibility. The first group recommended improved crossing visibility, where the focus should be on rural arterials. The second group proposed a requirement that an unspecified percentage of reflective clothing be worn to increase pedestrian visibility while crossing. The third group suggested improving crossing visibility through the addition of lit signage, flashing signals (e.g., RRFBs), and maintaining reflective striping.

For Activity 3, each group was directed, "As a group, discuss and identify possible systemic actions (regular implementation of treatments to workflows) or changes to design standards or policies. Make brief notes on the datasheet for your group. These ideas will be summarized and synthesized for the workshop wrap-up." After each group had submitted their datasheet, all sheets were summarized. Workshop participants were then given three votes each (indivudal, not group) and asked to vote on potential solutions. Each workshop participant had a top-priorty-, second-priority-, and third-priority vote. At the conclusion of the workshop, votes were counted and solutions prioritized.

A summary of the potential solutions for older pedestrians, and votes by priority, is given in Table 5. Table 5 represents individual participant counts. Five solutions received at least two top-priority votes; four of these received three top-priority votes. These solutions included the increased use of protected left-turns (i.e., eliminate permissive movements), illumination to increase pedestrian visibility, and eliminating driveway access near intersections. The solutions with two top-priority votes included shorter crossing distances/curb extensions/medians and lower speed limits. Four solutions received more second-priority votes. The solution with the highest number of second-priority votes was shorter crossing distances/curb extensions/medians (received six votes). The remaining solutions each received four second-priority votes, including adequate pedestrian crossings at regular intervals, illumination to increase pedestrian visibility, and eliminating free-flow turn and right-turn slip lanes. Lastly, in relation to third-priority votes, three solutions received more votes than others, each of which belong to the intersection-related category. Of these, shorter crossing distances/curb extensions/medians received six votes, and increasing the use of protected left-turns (eliminating permissive movements), and adequate pedestrian crossings at regular intervals each received three votes.

Discussion

Based on the crash data analysis and workshop findings, systemic treatments to improve older pedestrian safety were identified. The systemic approach allows agencies to implement the selected safety improvements at multiple locations with similar risk characteristics. As these countermeasures will be widely implemented, the focus was on selecting low-cost solutions. Thus, the selected countermeasures to improve older pedestrian safety included improving visibility and illumination, treatments for left turns, and shortening crossing distances. From the perspective of universal design, treatments aimed at benefiting older road users should benefit all road users. The focus here was to identify low-cost systemic treatments to improve older pedestrian safety, and these treatments were selected based on crash causes that were overrepresented in older pedestrian crashes. Additional details on specific countermeasures by crash cause are documented in the final technical report (*15*).

Improving Pedestrian Visibility and Illumination

Lighting is a significant factor in older pedestrian fatal and serious injury crashes. Crash data analysis showed that 20% of the crashes occurred in the dark with no street lighting, and an additional 8% and 5% of the crashes occurred during dawn and dusk, respectively, in which the ambient lighting is low. Improving pedestrian visibility and illumination was voted the top priority by the workshop participants. Countermeasures that improve illumination and the visibility of the pedestrian include improved lighting at intersections and near crossing locations and installing RRFB flashing beacons or other active warning devices such as flashing LED-mounted "Pedestrian Crossing" warning signs (*35*). Increased visibility of pedestrians to drivers has been shown to reduce crashes by up to 13% (*14*, *36*), and Monsere et al. estimated a CMF of 0.71 from the implementation of RRFBs (*37*).

Treatments for Left Turns

Vehicles turning left accounted for 19% of the older pedestrian fatal and serious injury crashes. Eliminating the use of permissive left-turns and increasing the use of protected left-turns could improve older pedestrian safety, as drivers often focus on the oncoming traffic looking for gaps and thereby miss the crossing pedestrians during permissive left-turns. This countermeasure also improves older driver safety by reducing their cognitive load. If permissive left-turns are used, adding a flashing yellow arrow indication for right turns can improve driver comprehension and behavioral responses in the presence of pedestrians (*38*). Slowing down left-turning vehicles may be another strategy to improve pedestrian safety. Cities such as Portland and New York have been using wedges and centerlines to decrease vehicle speeds and improve pedestrian safety. Implementing protected pedestrian phases and leading pedestrian intervals near older communities can also improve safety, as impleneta-tion of measures to separate pedestrians by time and space through utilizing protected or leading pedestrian intervals has been shown to reduce the expected number of crashes by up to 13% (*14*, *36*).

Shorten Crossing Distances

The proportion of older pedestrian fatal and serious injury crashes when the pedestrians were in the roadway was statistically significantly different when compared with the proportions of crashes for pedestrians between 25 and 44 years of age and between 45 and 64 years of age. Shortening the crossing distance for pedestrians will shorten their exposure time, thus increasing their safety. Specific countermeasures include installing pedestrian islands in the median to shorten the crossings and provide refuge, curb extensions on commercial streets and bus routes, and raised crosswalks and road diets near older communities (*35*). Pedestrian islands in the median of wide, busy streets have been shown to decrease the expected number of crashes by up to 14% (*14*, *36*), and raised crosswalks and road diets shown to decrease the expected number of crashes by up to 46% (*14*, *36*).

Conclusions

The objective of this research was to identify strategies to improve older pedestrian safety. To accomplish this objective, a review of the literature, crash data analysis, selection of potential countermeasures, and a workshop were conducted to arrive at recommendations for improving older pedestrian safety. Participants in the workshop were chosen based on their expertise and ability to make changes to design practice or policy. The recommendations include improving pedestrian visibility and illumination at intersections and near crossing locations, eliminating permissive left-turns and slowing down vehicles making left-turn maneuvers, and shortening crossing distances by installing median islands and curb extensions, thus reducing pedestrian exposure.

Although the findings and recommendations in this study were based on Oregon crash data, improving older pedestrian safety is an important issue nationwide in the United States. Older pedestrians have the highest risk for fatal or serious injuries and the recommendations developed in this study could be applicable in other areas. Additionally, this study has provided a data-driven framework for states to develop their own recommendations. Although the focus on this study was on identifying low-cost systemic treatments, consideration of treatments to address speeding may also be beneficial in improving older pedestrian safety and could be a focus for future work. Further, the crash data analysis was on crash data only. Fusing other data sources, such as exposure or land-use data, with the crash data may provide additional insights into older pedestrian serious injury crash behavior, which could be investigated in future work.

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Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: C. Monsere, D. Hurwitz. data collection: J. C. Anderson; analysis and interpretation of results: J. C. Anderson, S. Kothuri, C. Monsere, D. Hurwitz; draft manuscript preparation: J. C. Anderson, S. Kothuri, C. Monsere, D. Hurwitz. All authors reviewed the results and approved the final version of the manuscript.

Declaration of Conflicting Interests

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References

1. NHTSA. *Traffic Safety Facts: Older Population*. U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington, D.C. 2019.
2. Cottrell, W. D., and D. Pal. Evaluation of Pedestrian Data Needs and Collection Efforts. *Transportation Research Record: Journal of the Transportation Research Board*, 2003. 1828: 12–19.
3. Levi, S., D. M. De Leonardis, J. Antin, and L. Angel. *Identifying Countermeasure Strategies to Increase Safety of Older Pedestrians*. Report No. DOT-HS-811-798. National Highway Traffic Safety Administration, Washington, D.C., 2013.
4. Lobjois, R., N. Benguigui, and V. Cavallo. The Effects of Age and Traffic Density on Street-Crossing Behavior. *Accident Analysis and Prevention*, Vol. 53, 2013, pp. 166–175.
5. Kothuri, S., E. Smaglik, A. Kading, C. Sobie, and P. Koonce. Guidance on Signal Control Strategies for Pedestrians to Improve Walkability. *ITE Journal*, Vol. 88, No. 5, 2018, pp. 35–39.
6. Hewitt, B., and J. Evans. *Elderly Mobility and Safety - The Michigan Approach: Literature Review and Resource Inventory*. Southest Michigan Council of Governments, Detroit, 1999.
7. Kwigizile, V., J.-S. Oh, R. Van Houten, D. Prieto, R. Boateng, L. Rodriguez, A. Ceifetz, J. Yassin, J. Bagdad, and P. Andridge. *Evaluation of Michigan's Engineering Improvements for Older Drivers*. Report No. RC 1636. Michigan Department of Transportation, Lansing, 2015.
8. Boot, W., N. Charness, C. Stothart, M. Fox, A. Mitchum, H. Lupton, and R. Landbeck. *Aging Road User, Bicyclist, and Pedestrian Safety: Effective Bicycling Signs and Preventing Left-Turn Crashes*. Report No. BDK83 977-15. Florida Department of Transportation, Tallahassee, 2013.
9. Federal Highway Administration. Older Drivers and Pedestrians Special Rule. https://safety.fhwa.dot.gov/hsip/older/. Accessed November 16, 2021.
10. National Highway Traffic Safety Administration. Traffic Safety Facts: Occupant Protection in Passenger Vehicles. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812691.
11. National Highway Traffic Safety Administration. Traffic Safety Facts: Speeding. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812687.
12. National Highway Traffic Safety Administration. Traffic Safety Facts: Young Drivers. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812753.

13. University of North Carolina Highway Safety Research Center. *Crash Modification Factors Clearinghouse*. UNC HSRC, Chapel Hill, 2021.
14. Oregon Department of Transportation. *All Roads Transportation Safety: Crash Reduction Factors*. ODOT, Salem, 2020.
15. Monsere, C., J. C. Anderson, S. Kothuri, D. Hurwitz, and C. Chand. *Addressing Oregon's Rise in Deaths and Serious Injuries for Senior Drivers and Pedestrians*. Report No. FHWA-OR-RD-20-07. Oregon Department of Transportation, Salem, 2020.
16. ODOT Crash Analysis and Reporting Unit. *2017 Motor Vehicle Traffic Crash Analysis and Code Manual*. Oregon Department of Transportation Data Section, Salem, 2018.
17. Mokhtarimousavi, S., J. C. Anderson, M. Hadi, and A. Azizinamini. A Temporal Investigation of Crash Severity Factors in Worker-Involved Work Zone Crashes: Random Parameters and Machine Learning Approaches. *Transportation Research Interdisciplinary Perspectives*, Vol. 10, 2021, p. 100378. https://doi.org/10.1016/j.trip.2021.100378.
18. Zhou, X., P. Lu, Z. Zheng, D. Tolliver, and A. Keramati. Accident Prediction Accuracy Assessment for Highway-Rail Grade Crossings Using Random Forest Algorithm Compared With Decision Tree. *Reliability Engineering and System Safety*, Vol. 200, 2020, p. 106931. https://doi.org/10.1016/j.ress.2020.106931.
19. Pu, Z., Z. Li, R. Ke, X. Hua, and Y. Wang. Evaluating the Nonlinear Correlation Between Vertical Curve Features and Crash Frequency on Highways Using Random Forests. *Journal of Transportation Engineering, Part A: Systems*, Vol. 146, No. 10, 2020, p. 04020115. https://doi.org/10.1061/jtepbs. 0000410.
20. Li, L., C. G. Prato, and Y. Wang. Ranking Contributors to Traffic Crashes on Mountainous Freeways From an Incomplete Dataset: A Sequential Approach of Multivariate Imputation by Chained Equations and Random Forest Classifier. *Accident Analysis and Prevention*, Vol. 146, 2020, p. 105744. https://doi.org/10.1016/j.aap.2020.105744.
21. Abdel-Aty, M., and K. Haleem. Analyzing Angle Crashes at Unsignalized Intersections Using Machine Learning Techniques. *Accident Analysis and Prevention*, Vol. 43, No. 1, 2011, pp. 461–470. https://doi.org/10.1016/j.aap.2010.10.002.
22. Wang, X., and S. H. Kim. Prediction and Factor Identification for Crash Severity: Comparison of Discrete Choice and Tree-Based Models. *Transportation Research Record: Journal of the Transportation Research Board*, 2019. 2673: 640–653.
23. Li, D., P. Ranjitkar, Y. Zhao, H. Yi, and S. Rashidi. Analyzing Pedestrian Crash Injury Severity Under Different Weather Conditions. *Traffic Injury Prevention*, Vol. 18, No. 4, 2017, pp. 427–430. https://doi.org/10.1080/15389588.2016.1207762.
24. Zhang, J., Z. Li, Z. Pu, and C. Xu. Comparing Prediction Performance for Crash Injury Severity Among Various Machine Learning and Statistical Methods. *IEEE Access*, Vol. 6, 2018, pp. 60079–60087. https://doi.org/10.1109/ACCESS.2018.2874979.
25. Chen, M. M., and M. C. Chen. Modeling Road Accident Severity With Comparisons of Logistic Regression, Decision Tree and Random Forest. *Information*, Vol. 11, No. 5, 2020, p. 270. https://doi.org/10.3390/INFO110 50270.
26. Mokhtarimousavi, S., J. C. Anderson, A. Azizinamini, and M. Hadi. Improved Support Vector Machine Models for Work Zone Crash Injury Severity Prediction and Analysis. *Transportation Research Record: Journal of the Transportation Research Board*, 2019. 2673: 680–692.
27. Li, Z., P. Liu, W. Wang, and C. Xu. Using Support Vector Machine Models for Crash Injury Severity Analysis. *Accident Analysis and Prevention*, Vol. 45, 2012, pp. 478–486. https://doi.org/10.1016/j.aap.2011.08.016.
28. Alkheder, S., M. Taamneh, and S. Taamneh. Severity Prediction of Traffic Accident Using an Artificial Neural Network. *Journal of Forecasting*, Vol. 36, No. 1, 2017, pp. 100–108. https://doi.org/10.1002/for. 2425.
29. Mafi, S., Y. Abdelrazig, and R. Doczy. Analysis of Gap Acceptance Behavior for Unprotected Right and Left Turning Maneuvers at Signalized Intersections Using Data Mining Methods: A Driving Simulation Approach. *Transportation Research Record: Journal of the Transportation Research Board*, 2018. 2672: 160–170.
30. Yu, R., and M. Abdel-Aty. Anlyzing Crash Injury Severity for a Mountainous Freeway Incorporating Real-Time Traffic and Weather Data. *Safety Science*, Vol. 63, 2014, pp. 50–56. https://doi.org/10.1016/j.ssci.2013.10.012.
31. Hoare, J. How is Variable Importance Calculated for a Random Forest. https://www.displayr.com/how-is-variable-importance-calculated-for-a-random-forest/.Accessed June 6, 2019.
32. Dinsdale Lab. Random Forests. https://dinsdalelab.sdsu.edu/metag.stats/code/randomforest.html.Accessed June 6, 2019.
33. Harb, R., X. Yan, E. Radwan, and X. Su. Exploring Precash Maneuvers Using Classification Trees and Random Forests. *Accident Analysis and Prevention*, Vol. 41, No. 1, 2009, pp. 98–107.
34. Alteryx. Seeing the Forest: An Introduction to Random Forest. https://community.alteryx.com/t5/Alteryx-Knowledge-Base/Seeing-the-Forest-for-the-Trees-An-Introduction-to-Random-Forest/ta-p/158062.Accessed June 6, 2019.
35. FHWA. *Handbook for Designing Roadways for the Aging Population*. Report No. FHWA-SA-14-015. Federal Highway Administration, Washington, D.C., 2014.
36. Federal Highway Administration. Crash Modification Factors Clearinghouse. http://www.cmfclearinghouse.org/index.cfm.
37. Monsere, C., S. Kothuri, and J. Anderson. *Best Practices for Installation of Rectangular Rapid Flashing Beacons With and Without Median Refuge Islands*. Report No. FHWA-OR-RD-20-06. Oregon Department of Transportation, Salem, 2020.
38. Jashami, H., D. S. Hurwitz, C. Monsere, and S. Kothuri. Evaluation of Driver Comprehension and Visual Attention of the Flashing Yellow Arrow Display for Permissive Right Turns. *Transportation Research Record: Journal of the Transportation Research Board*, 2019. 2673: 397–407.